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Vegetation changes in Conservation Reserve Program lands in interior Alaska

Steven S. Seefeldt [a,*], Jeffery S. Conn [a], Mingchu Zhang [b], Phil N. Kaspari [c]

[a] USDA, Agriculture Research Service, Subarctic Agricultural Research Service, University of Alaska Fairbanks, Room 355 O'Neill Building, Fairbanks, AK 99775, USA
[b] Department of Plant, Animal, and Soil Sciences, University of Alaska Fairbanks, Room 321, O'Neill Building, Fairbanks, AK 99775, USA
[c] Cooperative Extension Service Delta District, University of Alaska Fairbanks, PO Box 349, Delta Junction, Alaska 99737, USA

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ABSTRACT

Over 14 million hectares of erosion prone cropland in the United States has been converted into grasslands through the Conservation Reserve Program (CRP) administered by the United States Department of Agriculture, however, studies of the effects of CRP enrollment on plant communities and subsequent plant succession are largely lacking. In Delta Junction, Alaska plant communities in CRP fields are transitioning from grasslands to shrub dominated plant communities, which are resulting in compliance problems with program regulations that state "fields must be maintained in a condition that permits easy conversion to cropland". To determine plant succession and how previous land management and soils might influence the transition, we measured plant populations in 20 CRP fields throughout Delta Junction using modified-Whittaker plots. These data were combined with data on current management practices, previous farming history, soils, soil properties, diversity indices, and time since land was cleared and analyzed with nonmetric multidimensional scaling ordination to determine factors that influence plant succession. Time in the CRP was the only factor consistently influencing plant succession. As time in the CRP increased, the planted introduced grasses brome grass (*Bromus inermis*) and red fescue (*Festuca rubra*) and the native pteridophyte (*Equisetum arvense*) decreased, whereas a native grass (*Calamigrostis canadensis*), five native forb, two native shrub, and three native tree species increased. Plant diversity increased at a rate of more than 2 species per 1000 m^2 per year. Regression analyses of plant species and plant groups using time in the CRP as the dependent variable resulted in the identification of outlier CRP fields with significantly more or less than expected covers of vegetation. All fields with these outliers had reasonable explanations for the differences in cover that were unrelated to the overall rate of plant succession. Current management practices will result in incompliant fields and different management practices that result in woody vegetation control is key to maintaining CRP fields in compliance.

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1. Introduction

In the past, farmers set aside cultivated land in the United States as a response to problems such as losses in soil fertility, salt build up, or farm surpluses. Recently, governments have provided subsidies for farmers to idle land (Millenbah et al., 1996). Over 14 million hectares of erosion prone cropland in the United States has been converted into grasslands through the Conservation Reserve Program (CRP) administered by the United States Department of Agriculture (Osborn et al., 1992). The CRP was established as part of the 1985 Food Security Act with a major goal of reducing soil erosion (United States Department of Agriculture, 1986). Typically, croplands are enrolled in the program for 10-year periods and owners receive an annual rental fee for planting and maintaining a permanent vegetation cover that prevents erosion and can be readily returned to cropping (United States Department of Agriculture, 1986). Alaska farmers have enrolled over 10,000 ha in CRP land, most of which is located near Delta Junction to control topsoil losses due to wind erosion (Schoephorster, 1973).

After the CRP was established, it was determined that vegetation under CRP management increased wildlife diversity such as butterflies in southwestern Minnesota where butterfly diversity was positively correlated with field width (Davros et al., 2006), birds (Johnson and Schwartz, 1993; Best et al., 1997; Delisle and Savidige, 1997), mammals (Chapman and Ribic, 2002) and herptofauna (Semlitsch and Bodie, 2003). Accordingly, the regulations of the CRP program were altered to require management techniques such as delaying mowing until after bird nesting to benefit wildlife (Natural Resource Conservation Service, 2003).

Management of land under CRP regulations is not simple abandonment with subsequent secondary succession that typically follows solving the erosion problem. Instead, there is active

* Corresponding author. Tel.: +1 907 474 1898; fax: +1 907 474 1813.
E-mail address: Steven.Seefeldt@ars.usda.gov (S.S. Seefeldt).

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management of these lands starting with the initial seeding of certain grass and/or forb species, fertilization, and weed control. Management program guidelines that are region specific are developed by the Natural Resource Conservation Service. In Alaska there were two enrollment periods (1986 and 1996). For the first CRP enrollment, guidelines called for planting all fields with a mix of 10 kg/ha brome grass (*Bromus inermus*) and 6 kg/ha red fescue (*Festuca rubra*). For the second enrollment, fields were typically planted with 4.4 kg/ha brome grass, 1.7 kg/ha timothy (*Phleum pratense*), 1.1 kg/ha clover (*Trifolium* spp.) and 1.1 kg/ha bluegrass (*Poa* spp.). One field (K) had a high population of native grasses and was not seeded or fertilized. For both enrollments, fields were fertilized with 110 kg/ha of 60-60-60 NPK prior to planting.

CRP rental fees are subject to various management objectives being met. Inspections are made to determine whether the vegetation meets standards of erosion prevention, wildlife habitat, and ease of conversion to cropland. Ease of conversion to cropland is the factor most related to compliance problems in Delta Junction as an unforeseen recruitment and growth of shrub and tree species is occurring. Regulations for managing these tree and shrub species consist of mowing every 2–3 years after bird nesting has finished (Helga Huelskoetter USDA—Farm Service Agency, personal communication). As mowing does not kill the shrub and tree species, many fields have developed thick shrub mats that will make it difficult to convert the fields back to agricultural production.

In most of the farmed fields of Delta Junction, relatively complete cropping histories are known since the first crop was planted after the forest was cleared. Because of erosion problems and the economics of farming in Alaska, a large proportion of this land was enrolled in the CRP. Among farms in Delta Junction, Alaska, there are considerable similarities in cropping systems, crop management, and CRP establishment methods, which made this an ideal study area for determining the impacts of time in the CRP on plant diversity and plant succession.

A few CRP fields have not followed the same rate of succession to trees and shrubs and we hypothesize that the delay in succession may be due to environmental, pre- or post-CRP management variables. In order to better understand and manage plant succession in interior Alaska, the objectives of this paper are to (1) describe the vegetation communities in Delta Junction CRP fields as it relates to time in the CRP, (2) determine whether variability in species assemblages are related to environmental and/or management variables, and (3) suggest improvements to CRP establishment and management techniques.

2. Materials and methods

2.1. Area description

The research sites are on or adjacent to the outwash plain of the Tanana River from 145°39′13″W, 64°0′30″N to 145°4′29″W, 63°58′53″N. The area ranges in elevation from 330 to 385 m and is in the Interior Bottomlands Ecoregion of the Alaska boreal forest (Gallant et al., 1995). We assumed the pre-farm vegetation was similar with a mix of white and black spruce (*Picea glauca* and *P. mariana*), balsam poplar (*Populus balsamifera*), quaking aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*) with associated understory species (Hulten, 1968). Soils are silt loam occurring on flat (0–3% slopes) outwash plains and terraces (Natural Resource Conservation Service, 2009). Climate is cold with average annual temperatures between −2 and −4 °C and average July temperatures about 16 °C. Annual precipitation varies from 250 to 300 mm. The frost-free period is 80–120 days.

The study area was sold and cleared from 1979 to 1982 as part of Delta Agricultural Projects I and II, when 34,000 ha were opened up for farmland in parcels that averaged 1000 ha (Lewis et al., 1979). Land clearing was conducted using pairs of bulldozers that pull an anchor chain between them to knock down trees. These trees were then piled in wind rows and burned in the winter. Roots were removed and the land was tilled at least twice with a 42 cm breaking disc the following year. Field B was cleared using the same methods in 1963. All resulting fields were farmed on a three-year rotation with two years of spring barley or oats followed with a year of tilled fallow. Based on farmer interviews, crop marketing challenges and high rates of wind erosion convinced many growers to enroll in the CRP program.

Table 1
Fertilizer and herbicide use in crops before CRP establishment in Delta Junction, AK.

Field	Fertilizer[a] (kg/ha)	Herbicide (active ingredient)
A and B	40–40–20–0	None
C, J, and K	100–20–60–4	In crop alternate 0.5 kg/ha 2,4-D with 0.06 kg/ha Dicamda + 0.2 kg/ha MCPA in fallow 0.38 kg/ha glyphosphate
D and E	65–40–20–10	In crop alternate 0.5 kg/ha 2,4-D with 0.5–0.75 kg/ha MCPA
F and G	40–20–20–0	None
H and I	50–23–37–10	One application of 0.5 kg/ha 2,4-D
L–T	70–50–0–0	0.5 kg/ha 2,4-D + 0.25 kg/ha MCPA

[a] N–P–K–S.

Twenty CRP fields were chosen throughout the Delta Junction farming area. There were two opportunities for farmers to enroll in the CRP. Thirteen of the fields were enrolled in the first round and planted to CRP 18–20 year before the study. The remaining seven fields were enrolled in the second round and planted to CRP 6–9 year before the study. Farming history obtained from grower interviews in the winter of 2006/2007 and data on file at the USDA-Farm Service Agency confirmed that growers; used similar equipment for disking (23 cm field cultivator) and planting (double disk drill with press wheel); and planted at similar rates (110 kg/ha) and row spacing (15 cm). Fertility management and herbicide use differed among growers (Table 1). The number of years since forest clearing, number of cropping years, number of fallow years, and number of years the field had been in CRP were also determined.

Because of the short growing season, planting all occurred at the same time.

As some farms own and manage more than one field in this study, we thought to compare fields based on farm ownership, but as several of these fields had changes in ownership over the years, it was not possible to compare differences based on farm ownership. Additionally in the CRP fields studied, it was determined that the farmers were extremely uniform in farm management. Each planted similar crops (barley and occasionally oats), with the same rotation (2 year with crops followed with a tilled fallow), and used similar equipment and seeding rates.

2.2. Sampling methods

To sample plant cover and diversity in the 20 CRP fields, modified-Whittaker plots (Stohlgren et al., 1995) were used (Fig. 1). The individual CRP fields were rectangular and one plot was placed in each half of a field in areas that looked representative of that half of the field. There were three exceptions to this procedure: Field F had four modified-Whittaker plots and fields N and O had one each. The modified-Whittaker plot was chosen as it samples a large area (0.1 ha) and is useful for detecting less abundant plant species (Stohlgren et al., 1998).

Sampling was conducted in mid-August 2005 when most plants were in flower and fruit to aid in identification. A sampling protocol described by Stohlgren et al. (1998) was used. At each sampling location a 20 m × 50 m plot (1000 m^2) was established.

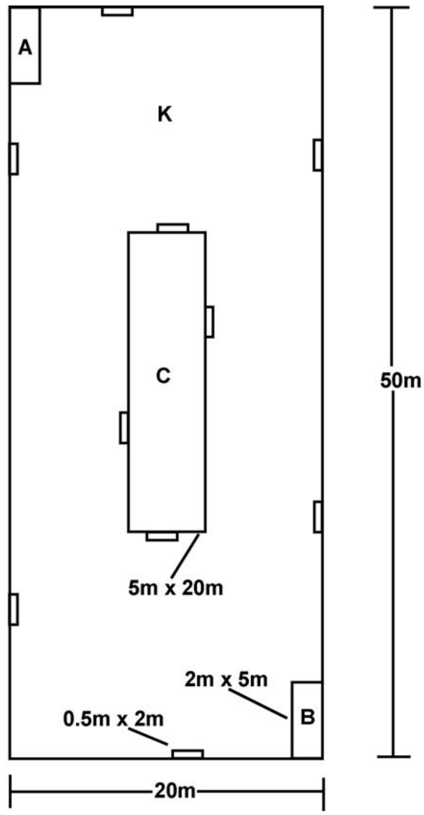

Fig. 1. Sampling layout for the modified-Whittaker plots with ten 1-m^2 plots, two 10-m^2 plots (A and B), one 100-m^2 plot (C), and one 1000-m^2 plot (K).

All plot corners were located using a global positioning system (±3 m) to facilitate future re-sampling. Nested within this plot were: one 5 m × 20 m plot (100 m^2), two 2 m × 5 m plots (10 m^2) and ten 0.5 m × 2 m plots (1 m^2) (Fig. 1).

In each 1 m^2 plot, percent cover of each plant species (at maximum crown diameter), percent bare ground, and other non-plant components (rock, litter, feces and wood) were estimated visually. All plant species found in the 10 and 100 m^2 plots were recorded and any new plants found in the 1000 m^2 areas were added to the list of species already identified in the smaller plots. Percent cover was not determined in the 10, 100, and 1000 m^2 plots. The resulting plant list was used to generate species area curves (number of species = $mx + b$, where m is the slope of the line, x is log area and b is the y-intercept) (Stohlgren et al., 1995). As the CRP field was the experimental unit, all analyzed plant measures were averages from the modified-Whittaker plots in each field.

Species richness was the average of the total species from each of the modified-Whittaker plots in each field. Species diversity in the fields was compared using Shannon's index and Simpson's index (Ludwig and Reynolds, 1988). Shannon's index (H') for a sample is defined as

$$\hat{H}' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right],$$

where n_i is the cover of the ith species of S species in the sample and n is the total cover of all species in the sample. Simpson's index (λ) for a sample is defined as

$$\lambda = \sum_{i=1}^{s}\frac{n_i(n_i-1)}{n(n-1)}.$$

The values from these indices were then combined in a method recommended by Ludwig and Reynolds (1988), which differ from the similarity analysis of the Jaccard's coefficient by weighting the abundant ($N1$) and very abundant species ($N2$). $N1$ was calculated as

$$N1 = e^{H'},$$

and $N2$ was calculated as

$$N2 = \frac{1}{\lambda}.$$

With the values from the above equations, a modified Hill's ratio can then be determined as a measure of evenness ($E5$; Ludwig and Reynolds, 1988). $E5$ was calculated as

$$E5 = \frac{(1/\lambda)-1}{e^{H'}-1} = \frac{N2-1}{N1-1}.$$

As $E5$ approaches zero one species becomes more dominant in the total cover component. Higher values of $E5$ indicate a more even division of cover among the species in the sample area.

Soil type was determined for each field using a recent soil survey (Natural Resource Conservation Service, 2009). At the end of August 2005, soil was collected from each of the 40 plots. Two soil pits (about 25 cm (width) × 30 cm (length) × 30 cm (depth)) were dug at random locations in each modified-Whittaker plot. A slice of soil (5 cm (width) × 20 cm (length) × 15 cm (depth)) was taken from the edge of the soil pit and mixed thoroughly in a plastic container. A representative soil sample (~0.5 kg) was then taken and sent for analysis of total C, total N (LECO CHN 1000 Analyzer, St. Joseph, MI, USA), and total P (perchloric acid digestion followed by ICP-AES (Perkin Elmer Optima 3000XL)) determination as well as for Mehlich 3 extractable P, K, Ca, Mg, Na, Fe, Cu, Zn, and Mn (Mehlich, 1984). Soil bulk density and plant litter depth was not measured. Under cold semi-arid climatic conditions in interior Alaska, changes in soil chemical properties for different land uses may require longer time frames than the 20 years that some of these fields have been in the CRP. These CRP fields are undisturbed and there is an absence of large soil fauna (e.g. earthworms) to mix organic matter. Therefore there would be very little change to mineral structure and bulk density over the 18 years of this study. Litter depth in these fields varies considerably in short distances and decomposition is very slow at high latitudes, therefore it was not included in our measurements. However, the amount of litter cover was measured.

In August 2007, all 20 fields were rated by a four member team comprised of personnel from the Natural Resources Conservation Service, Farm Services Administration, Alaska Department of Fish and Game, and University of Alaska Fairbanks Cooperative Extension Service. The fields were rated on a scale of 1–5 (with 5 = excellent and 1 = non-compliant) for the following attributes: (1) ease of field conversion back to cropping; (2) wildlife habitat quality; (3) erosion control; and (4) overall condition. Team members did not compare observations until the end of the day and subsequent analyses determined there were no observer biases. As all fields scored equally well for erosion control (5 = no erosion evident), these data were dropped from the analysis.

2.3. Data analysis

The nonmetric multidimensional scaling (NMS) ordination method in PC-ORD Version 4.41 (McCune and Mefford, 1999) was used to analyze the relationship among species importance values and environmental/management variables and to confirm that time in CRP was the most important dependent variable in explaining vegetation change. Species importance values were calculated as the average of relative cover and relative frequency using data from the 1 m^2 sub-plots in the modified-Whittaker plots. Uncommon species that were found in only one field and had importance values less than 1% were deleted before the analysis.

The NMS ordination was conducted in autopilot mode, allowing the program to choose the best solution of starting configurations and number of dimensions to achieve the lowest stress value (McCune and Grace, 2002). The Sorensen (Bray-Curtis) distance measure and random starting configurations was used, with 40 runs of real data and 50 runs of randomized data to perform a Monte Carlo test of significance. Relationships between the NMS axes and the environmental/management variables were examined using Kendall correlations. Vectors on the ordination plots show the magnitude and direction of the major environmental/management variables in the ordination space. The critical value of Kendall's coefficient (τ) at the 0.05 level of significance for a two-tailed test is 0.326 for $n = 20$.

Linear regression analyses were conducted with significantly related plant species and groupings of species using time in the CRP as the dependent variable. In these regression analyses, fields were sometimes determined to be outliers from the regression using the R option in SAS PROC REG (outside the 97.5% confidence interval). An ANOVA was then used to determine the difference in these plant species and groupings of species based on which of the two entry times the field was enrolled in the CRP. Outlier fields were included in this analysis. The management information from the outlier fields was used to offer clues that might explain why these fields were not going through plant succession at predicted rates.

3. Results

3.1. Plant communities

There were 107 plant species (including eight unidentified species) found in the plots (Appendix A). In the individual modified-Whittaker plots (1000 m^2), species richness ranged from 10 to 37 species. In the 1 m^2 sub-plots there were a total of 78 species and, of these, 28 were not used in species ordination (Fig. 2) as they only occurred in one field and had an importance value less than 1%. Ten fields were herbaceous with over 80% of the vegetation cover represented by grass and forb species. Six fields had vegetation cover that was over 50% woody. The remaining 4 fields were an even mix with an average vegetation cover of 20% grass, 40% forb, and 40% woody species.

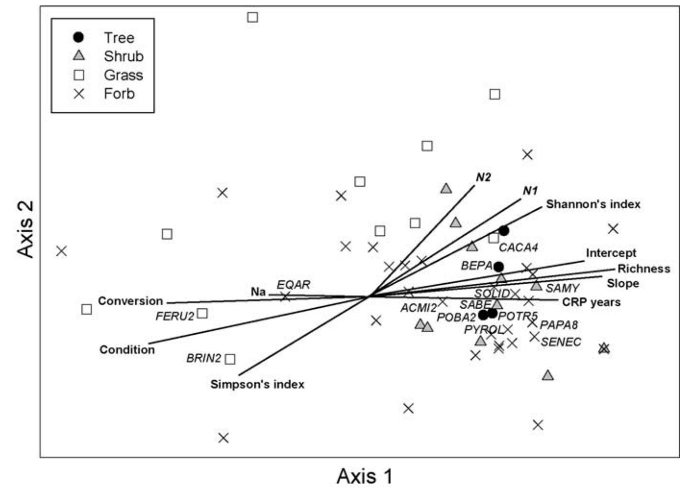

Fig. 2. Nonmetric multidimensional scaling ordination of common species grouped by functional type and biplot vectors showing significant variables in the Conservation Reserve Program study in Delta Junction, AK. Species significantly correlated with ordination axes are identified in the figure with species letter code abbreviations that are listed in Appendix A.

3.2. Ordinations

The first ordination axis explained 78% of the variability in plant community composition in the CRP fields and the second axis explained an additional 10%. Except for number of years in CPR, no cropping variables (years cropped, years in fallow, herbicide use, and years since the field was first cleared from the forest) were correlated with either axis (data not shown). Based on the ordination, the number of years the field was in the CRP was positively correlated ($\tau = 0.57$) to the first axis.

The first ordination axis was weakly negatively correlated to soil Na ($\tau = -0.40$). Except for Na, soil variables were not correlated with the first or second ordination axes. Sodium levels were reduced with increasing years in CPR. Soil characteristics of the different CRP fields are given in Table 2.

Positively associated with the first axis were importance values of three tree and two shrub species, paper birch (*B. papyrifera*),

Table 2
Soil properties for Conservation Reserve Program fields in Delta Junction, AK.

Field	Soil type[a]	Total C	Total N	Total P	P	K	Ca	Mg	Na	Cu	Zn	Mn	Fe
		%			ppm								
A	NaA	2.6	0.1	0.06	14	63	1100	150	10	2.2	0.8	26	540
B	Sc	4.1	0.2	0.07	27	148	1400	140	6	3.8	2.1	13	570
C	NaA	3.0	0.2	0.06	25	120	1500	250	11	1.5	0.9	17	520
D	VkA	2.9	0.1	0.05	8	92	1200	210	12	1.9	0.6	14	560
E	VkA	2.8	0.2	0.06	5	73	1200	220	14	2.3	0.6	12	580
F	BaB	1.4	0.1	0.06	25	88	800	200	14	1.3	0.5	12	490
G	VkA	3.2	0.2	0.05	4	71	1400	290	17	1.8	0.7	18	530
H	VkA	3.7	0.2	0.06	10	109	1300	220	15	1.9	1.1	9	550
I	VkA	10.6	0.6	0.12	6	78	3100	370	21	1.7	1.2	24	540
J	VkA	3.4	0.2	0.06	6	70	900	130	14	1.6	0.6	12	500
K	VkA	3.6	0.2	0.07	16	65	900	105	12	1.7	1.4	17	490
L	VkA	3.8	0.2	0.06	11	39	1300	150	19	1.8	0.7	14	450
M	VkA	2.4	0.1	0.05	4	48	1000	190	16	2.3	0.4	13	480
N	RcA	1.6	0.1	0.04	8	33	1000	200	19	2.2	0.5	21	450
O	RcA	2.5	0.1	0.05	23	85	1900	340	19	2.2	2.4	23	560
P	RcA	3.2	0.2	0.07	42	80	1700	190	23	2.5	2.7	23	590
Q	219	3.4	0.2	0.06	6	86	1700	260	23	2.8	0.8	10	560
R	219	3.6	0.2	0.06	3	39	1400	210	24	2.6	0.9	9	560
S	217	2.9	0.2	0.06	29	78	2300	270	18	3.1	2.7	23	470
T	217	2.8	0.1	0.06	16	66	1600	240	21	2.3	1.0	13	530

[a] *Abbreviations:* NaA, Nenana silt loam; Sc, Salchaket very fine sandy loam; VkA, Volkmar silt loam; BaB, Beales silt loam; RcA, Richardson silt loam; 219, Moosehead silt loam; 217, Lupine silt loam.

balsam poplar (*Populus balsamifera*), quaking aspen (*P. tremuloides*), Bebb's willow (*Salix bebbiana*), and blueberry willow (*S. myrtillifolia*) (τ = 0.52, 0.38, 0.58, 0.68, and 0.40, respectively). Also positively correlated with the first axis were importance values of five native forb species: common yarrow (*Achillea millifolium*), grass of Parnassus (*Parnassia palustris*), wintergreen (*Pyrola* spp.), common groundsel (*Senecio lugens*), and goldenrod (*Solidago* spp.) (τ = 0.48, 0.44, 0.37, 0.40, and 0.55, respectively). Bluejoint reedgrass (*Calamagrostis canadensis*), was also positively correlated to the first axis (τ = 0.41). Both introduced grass species, brome grass (*Bromus inermis*) and red fescue (*F. rubra*) and the native field horsetail (*Equisetum arvense*) were negatively correlated to the first axis (τ = −0.54, −0.59, and −0.36, respectively).

Positively correlated with the second axis were the native plants bluejoint reedgrass (*Calamagrostis canadensis*), sedge (*Carex* spp.), wheatgrass (*Elymus trachycaulus)*, and Siberian yarrow (*Achillea siberica*) (0.38, 0.35, 0.39, and 0.42, respectively). The introduced plant brome grass was negatively correlated to the second axis (τ = −0.48).

3.3. Plant diversity/eveness measures

Plant diversity/eveness measures; species richness, Shannon's index, *N*1, *N*2, and intercept and slope of the species area curve were positively correlated with the first ordination axis (Fig. 2), with τ = 0.62, 0.46, 0.42, 0.35, 0.67 and 0.64, respectively. The abundance measures *N*1 and *N*2 were positively correlated (τ = 0.36 and 0.41, respectively) with the second axis. Simpson's index was negatively correlated with the first axis (τ = −0.36). *E*5 was not correlated with either axis.

Two rating team CRP scores, ease of conversion back to a crop and overall condition of the CRP field, were negatively correlated with the first axis (τ =−0.63 and −0.64, respectively).

3.4. Response of plant species and groups of plants to time in the CRP

Of the 18 plant species identified as being positively or negatively correlated with axes 1 or 2 in the NMS ordination, only 5 were significantly different from zero in a regression analysis with time in the CRP as the dependent variable (Table 3). Additionally, there were 5 plant groupings where cover was different from zero when regressed against time in the CRP (Table 3). There were typically 2–3 outlier fields that had significantly different amounts of cover from the fields with similar entry times. These outlier fields were identified in the analyses as they might serve as examples of how plant succession rates might be increased or decreased.

3.5. Cropping variables and outlier fields

Fertilization regimes were variable from farm to farm and year-to-year, however, these differences did not translate into differences in soil fertility at the time of the study. As the farming practices were so similar, we were not able to uncover statistical differences among these cropping variables that occurred prior to conversion to the CRP.

Generally vegetation in the CRP fields that were in the first entry and had been in CRP for 18–20 years were 27%, 30%, and 43% grasses, forbs, and woody, respectively; whereas the second entry fields (6–9 years in the CRP) were 78%, 18%, and 4% grasses, forbs, and woody, respectively. This is a clear transition from grass dominated to woody dominated fields. A careful look at the outlier fields does reveal some important as well as inconsequential differences in these fields that lead to some critical insights (Table 3). As an example of inconsequential differences the G and I fields have 2 and 3 times as much *Achillea millifolium* cover (1.3% and 1.5%, respectively) as the average field in the first entry (0.53%). Similarly, the M field had more than twice as much *P. tremuloides* cover (10%) as other fields in the first entry (4%), but was otherwise no different in average cover for all other measured variables. Given the number of fields and plant species measured, these differences could well be within random chance and be an example of a type 1 error. The I field, a slightly moister site resulting in more rapid plant growth, had more total vegetation cover and significantly more woody vegetation cover (52%), than the typical fields in the first CRP entry (19%). This also resulted in ease of conversion to cropping and overall condition scores that were 'out of compliance' with regulations. The additional moisture resulted in bushier woody vegetation, but the following year this site was mowed and the woody cover, based on a more basal area measure, were similar to other fields with the same time in the CRP.

The P field had twice as much *B. inermis* and *F. rubra* cover as the average for second entry CRP fields (25% and 17% versus 12% and 9%, respectively). This field had 42 ppm phosphorus (Table 2), which would have enhanced grass growth compared to other CRP fields as >50 ppm phosphorus is considered adequate for plant growth (Follett and Wilkinson, 1995), and all other fields had reduced amounts of this element (Table 2). The S and T fields were both in the second entry. The S field had more total perennial cover (56%) and total herbaceous cover (58%) than the averages for the second entry fields (37% and 37%, respectively); whereas the T field had less (21% and 21%, respectively). Overall cover for the S field was 63% compared to the T field which was 21%. In discussions with the land manager, he reported that the year the S field was planted into the CRP; the climate was exceptionally good resulting

Table 3
Regression equations, percent cover for plant species and groups of plants correlated to time fields were in the Conservation Reserve Program, and outlier fields in Delta Junction, Alaska.

Species	Slope	Intercept	*P*	r^2	Cover		Outlier fields
					First entry[a] (%)	Second entry (%)	
Salix bebbiana	0.84	−5.1	0.008	0.33	10.3	1.2	I, R
Populus tremuloides	0.33	−2.1	0.009	0.33	4.0	0.2	I, M
Achillea millifolium	0.04	−0.2	0.026	0.25	0.5	0.1	G, I
Bromus inermis	−0.79	18	0.008	0.33	4.0	12.1	K, P, R
Festuca rubra	−0.54	13	0.02	0.27	3.0	8.6	K, P, R
Species groups							
Non native grasses	−1.2	26	0.0002	0.54	4.2	17.7	K, R
Non native	−1.2	27	0.0003	0.52	4.7	18.6	K, R
All perennial	−1.2	45	0.013	0.30	22.7	36.6	R, S, T
All non woody	−1.2	0.5	0.014	0.29	22.8	36.9	R, S, T
All woody	1.6	−9.6	0.003	0.41	19.2	1.6	B, I, R

[a] First year entry fields were enrolled in the CRP 18–20 year and second entry fields were enrolled in the CRP 6–9 year before data was collected.

in excellent germination and establishment of the planted species. The S field was the only one that had been seeded into the CRP that year. The increased cover of herbaceous material in the S field did not correspond with a decrease in woody cover. Two years after the S field was planted, the same grower planted the T field. He reported that poor timing of rain resulted in little successful emergence of planted species in any of the fields he planted that year. The decreased cover of herbaceous cover did not correspond with an increased woody vegetation cover.

The K field was in the second entry and has reduced amounts of *B. inermis* and *F. rubra* cover (2.1% and 0.05%, respectively) compared to the averages for the second entry (12% and 9%, respectively) and these value are reflected in reduced cover of non native grasses and non-native plant species (both 3.9%) compared to other second entry fields (18% and 19%, respectively). The land manager for this field did not plant *B. inermis* and *F. rubra* or any other species when preparing the field for the CRP as he had observed that he had an excellent stand of native grasses (mostly *Calamagrostis canadensis* and *Carex* spp.). His only treatment was to broadcast fertilizer.

The R field had 8 outliers in Table 3. The R field had been in the CRP for 18 years and yet 69% of its vegetation cover was grass, 28% was forb, and 3% was woody compared to 27%, 30%, and 43% respectively for other first entry fields. Indeed, second entry fields had vegetation split into 78% grass, 18% forb, and 4% woody, which is not different from the R field. The vegetation in this field was not going through succession at the same rate as the other first entry fields. In scores of ease of conversion to crops and overall condition, these fields were similar to fields that were in the second CRP rotation. No measured or recorded factors could explain any differences either between this field and an adjacent field (Q) or among the other fields in the first CRP entry. A follow-up discussion with the land manager revealed that after 10 years in the CRP the farmer pulled the field out of the program, disking it in the autumn of 1997 and the following spring, before planting it to oats. The farmer then re-enrolled the field in the CRP, replanting it to *B. inermis* and *F. rubra* and fertilizing with the standard mix in the spring of 1998. The additional farming, which removed woody vegetation, essentially reset the succession process, putting this field in the same category as the second entry fields, where it is no longer an outlier.

Based on regression of expert evaluation scores, as time in the CRP increased and the percent of woody vegetation increased, ease of conversion to crops was determined to be increasingly difficult. Indeed, based on the regression, most fields would be out of compliance with regulations for both ease of conversion to crops and overall condition after 32 year. To keep these fields in compliance with CRP regulations for easy conversion back to cropping, fields need to be managed to reduce the shrub component. An occasional tillage or herbicide application may be needed to reduce shrub and tree invasion. The use of a management strategy to remove woody vegetation or other functional groups from these CRP fields would provide researchers with the opportunity to conduct removal experiments.

4. Discussion

Natural or human-caused perturbations result in altered vegetation and restart a series of plant community transitions. Extreme examples of this are primary succession on lava in Hawaii (Atkinson, 1970), secondary succession on abandoned cropland (Oosting, 1942), and xerarch succession behind retreating glaciers (Crocker and Major, 1955) where bare ground transitions through a series of plant communities. In these examples, temporal changes in plant diversity occur without management inputs. On cultivated lands such as those used in this study, the crops grown, the management systems used, and climate all influence the suite of associated plant species that will grow on any given piece of land (Haas and Streibig, 1982). Management can increase plant diversity, as was observed in the selection for herbicide resistant weeds (Haas and Streibig, 1982; Holt et al., 1993). In contrast, management can decrease plant diversity as occurred when management practices led to the introduction of non-indigenous invasive plant species, such as downy brome (*Bromus tectorum*) in the American west, which alters fire cycles resulting in a vegetation transition to new plant communities that did not include many native species (Pellant, 1990; Peters and Bunting, 1994). The ability to predict the consequences of management on subsequent plant communities has been the goal of many as it should lead to decisions that will trend towards more functional ecosystems (Naeem et al., 2002).

4.1. Soils and soil property variables

There are seven soil types in the study area, six are silt loams and the seventh is a very fine sandy loam (Sc) occurring in the B field (Table 2) (Natural Resource Conservation Service, 2009). Except soil Na which was negatively correlated with the first axis, most of the fields have similar nutrient profiles (Table 1) and these similarities reflect the lack of their impact on plant communities. Sodium is regarded as a functional plant nutrient (Subbarao et al., 2003). Unlike other essential plant nutrients, Na uptake is plant specific. Some plant species, such as sugar beet (*Beta vulgaris altissima*) can use Na as a K replacement. But others such as timothy are very sensitive to Na, with moderate levels of soil Na causing growth reduction (Marshner, 1998). In our study, these plant species that were positively correlated to the first axis (e.g. common yarrow), may absorb less Na from soil as compared to the plant species (e.g. brome grass) that were negatively correlated with the first axis, resulting in a relative increase of Na concentration in soil. The measured soil properties did not change as a consequence of time in the CRP. There was an expectation that soil properties would explain some of the plant variability, but the recent process of clearing the land, burning off the surface organic material, and exposing the mineral soil may have enhanced soil uniformity.

4.2. Plant populations

As time in the CRP increased, the number of plant species increased at a rate of more than two per year in a 1000 m^2 area. This increase in plant species, as well as an associated increase in abundant, and very abundant species numbers is typical of plant succession from old fields and disturbances in the early stages (Oosting, 1942).

Not unexpectedly, species assemblages and diversity/eveness changed with time in CRP. Increases in richness were positively associated with both the slope and the *y*-intercept of the species area curve. The number of abundant ($N1$) and very abundant ($N2$) species increased as time in CRP increased. It is important to note that increases in species richness did not mean there were only more rare species, but that other plant species were becoming abundant. When there were 10 species, 30% of them were abundant or very abundant, when there where 36 species, 30% of them were abundant and 20% of them were very abundant. The $E5$ measure, also referred to as the modified Hill's ratio, ranges from 1 in a completely even community of species to 0 in a community with one plant species (Alatato, 1981). The evenness ($E5$) of the plant community declined from 0.86 to 0.71 with increases in time in the CRP. Although a value of 0.71 still represents an evenly spread community of plant species, shrub and tree species are beginning to dominate, despite repeated mowing.

Certainly an argument could be made that at this point in plant community development this change in evenness is irrelevant. Shannon's index is another measure of evenness where 0 represents a single species plant community and increases in the index reflect more even plant communities. In this study evenness as calculated with Shannon's index increases from 1 to 2.1 as time in CRP increased from 6 to 20 year. Simpson's index is a measure of the probability that two plants drawn at random in a community will be the same species. Values range from 0 to 1, with one representing a monoculture. In this study Simpson's index declined from 0.4 to 0.15 as time in CRP increased from 6 to 20 year, indicating an increase in plant diversity.

Plant diversity, an important component of the vegetation community, may be directly related to wildlife habitat and community stability and resilience (Naeem et al., 2002). However, the rating team results did not indicate that the CRP fields differed in suitability for wildlife over time, even though the fields differed in diversity and plant species present. This may be because the raters were not evaluating the fields on the basis of one wildlife species but for wildlife in general. The early grass dominated plant communities were good habitat for wild bison and the later shrub dominated plant communities were good habitat for moose. Studies on the effects of conversion of cropland to the CRP on subsequent plant communities are largely lacking throughout the USA. An exception is Felix and Owen (2004), who studied the differences in weed seedbanks between fields that had been in the CRP for 12 years and adjacent cropland in Iowa. Seed banks of weeds were generally smaller under CRP management than in adjacent cropped fields.

4.3. Plant succession

The first axis represents a succession gradient (Fig. 2). In these fields, the planted introduced species, brome grass and red fescue were declining and many native plant species were increasing as time in the CRP increased, indicating the ability of the native plant flora to re-establish after cropping. The recovery of native vegetation is similar to early plant succession stages described for floodplains (Walker et al., 1986; Viereck et al., 1993) as well as to post-logging with slash burning (Dyrness et al., 1988) in the boreal forest. On floodplains, open willow communities that transition into closed alder are found 5–20 year after the last flooding event (Viereck et al., 1993) however, alder was not a common species in our plots (Appendix A). In the case of succession after a fire, shrubs and tree saplings are common within 5 years (Johnstone et al., 2004) and the plant community in older CRP fields resembled the plants described by Dyrness et al. (1988). Plant succession in the CRP fields in the Delta Junction area seems to be occurring in a manner similar to that of natural systems, despite multiple years of farming, and if left unmanaged would return to a plant community that could be indistinguishable from the surrounding undisturbed bottomland forest.

5. Conclusion

Our hypothesis was that plant succession in Delta Junction CRP fields can be predicted based on a few key factors. The results of this study indicate that time in the CRP was the only factor consistently influencing plant succession. In describing the vegetation communities (objective one) we found that fields more recently enrolled in the CRP were dominated by grasses with reduced plant species richness, whereas older CRP fields increased in plant species richness at a rate of over two plant species per 1000 m^2 per year. There was no indication that current management practices, previous farming history, soils, soil properties, or time when land was cleared had any impact on altering the rate of succession (objective 2). As woody species increase in importance (frequency and abundance) it is becoming increasingly difficult to meet compliance standards for the CRP. If projections of the regression lines are correct, most fields will be non-compliant with the CRP based on overall condition and ease of returning to cropping 32 years after establishment. Although after 32 years, these fields will probably still be providing excellent erosion control and wildlife habitat. This study was not designed to result in suggestions to improve CRP establishment and management techniques (objective 3), but the results give an important indication that woody vegetation control is key to maintaining CRP fields in compliance with regulations. To that end research is being conducted to manage woody vegetation in Delta Junction, Alaska CRP fields.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.agee.2009.09.001.

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